

# ***Improvements in the NIST Calibration Service for Thermal Converters***

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<http://www.acdc.nist.gov>



# Outline

## ■ Problems:

Three calibration services for thermal converters

- Customer service
- CCEM issues

Low-voltage uncertainties

- Too many scaling steps

Ac current standards

## ■ Solutions:

Consolidate all thermal converter calibrations

Develop intrinsic standard for millivolt metrology

Continue development of high-current MJTCs

# Too Many Projects!

- **Fundamental Electrical Measurements:**

200 mV → 1000 V, 10 Hz → 1 MHz

- **Applied Electrical Measurements:**

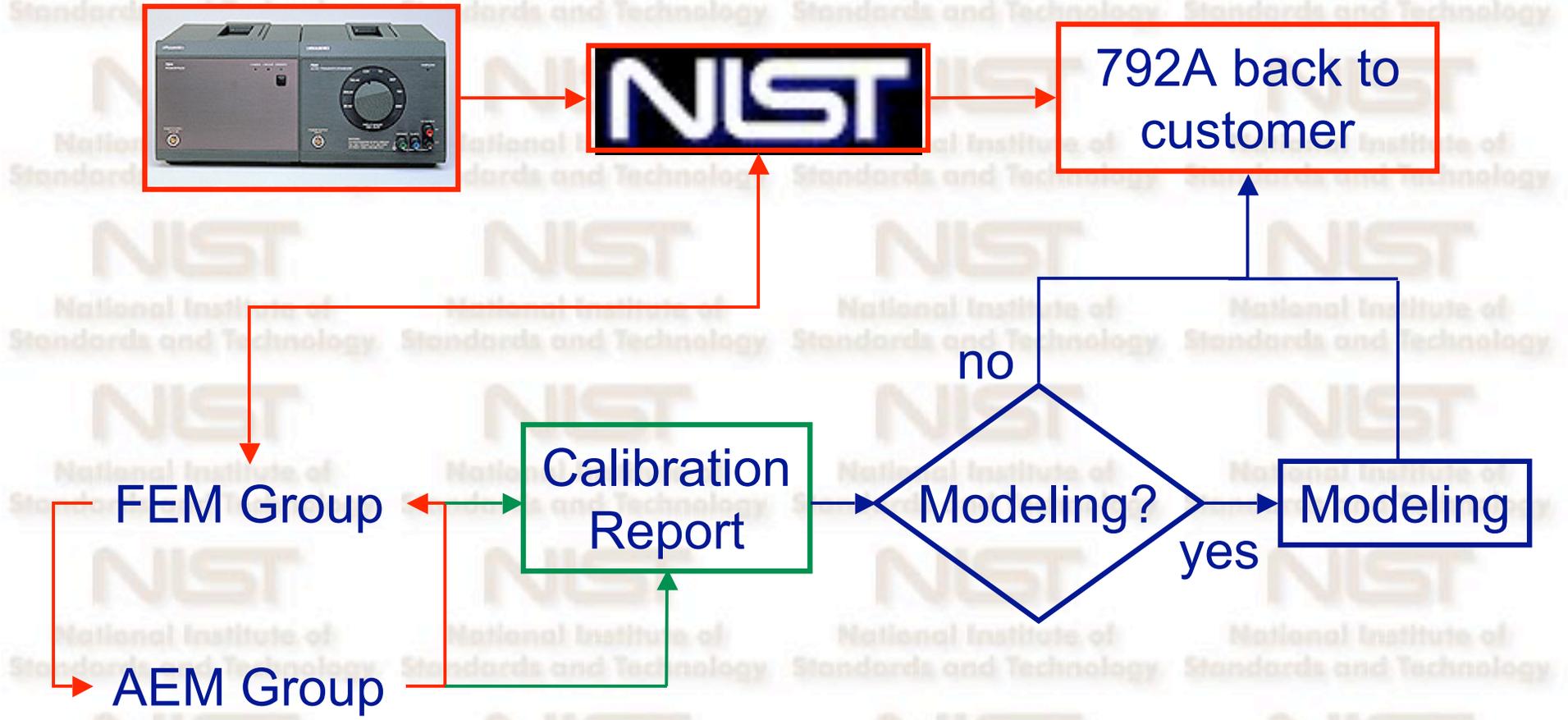
2 mV → 200 mV, 10 Hz → 1 MHz

- **Radio Frequency Electronics**

100 mV → 200 V, 30 kHz → 100 MHz

200 mV → 7 V, 100 MHz → 1 GHz

# Calibration Route (Fluke 792A)



# Calibrations Can Take a Very Long Time!!

- Unhappy customers
- Higher cost
- Bad publicity

## Solution

- Move the calibration service for Fluke 792A transfer standards to the FEM Group

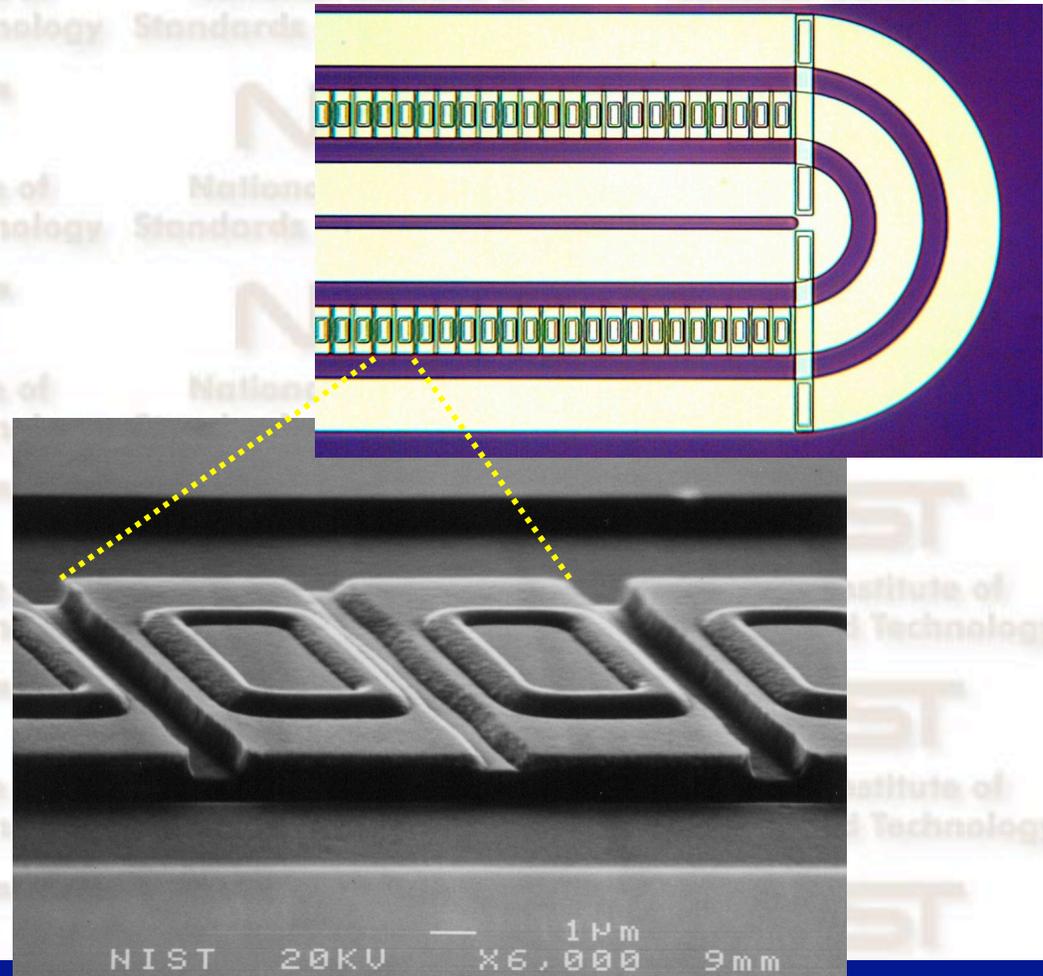
One source for Fluke 792A calibrations

To do this, we must demonstrate performance equal to AEM Group

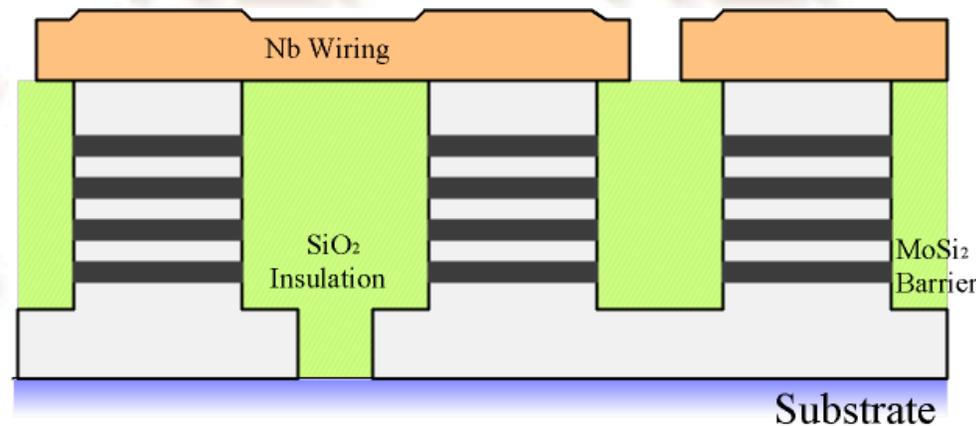
- Intrinsic ac standard
- Use MJTCs to reach 100 mV level
- Direct comparison of 792As

# JAWS - The Future of AC Metrology

- Two Josephson arrays - 2560 junctions each
- Ac and dc voltages up to  $170 \text{ mV}_{\text{rms}}$
- Optimized for  $100 \text{ mV}_{\text{rms}}$
- Based on stacked, Nb-MoSi<sub>2</sub>-Nb junctions
- Collaborators:  
S. Benz, C. Burroughs,  
P. Dresselhaus  
NIST, Boulder, CO

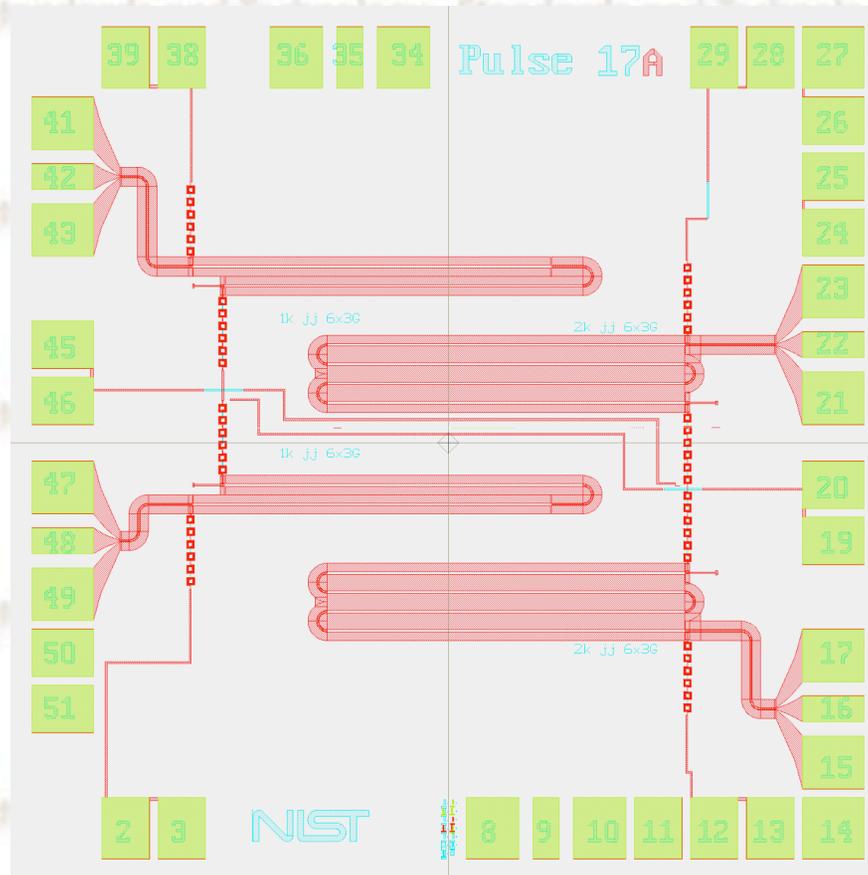


# Stacked Junctions



- Planar junctions exploit uniformity of thin-film deposition
- Dry-etchable barrier material (not PdAu)
- Vertical etch profile
- Planarize dielectric for very tall stacks

# JAWS - Chip Design



# JAWS - The System



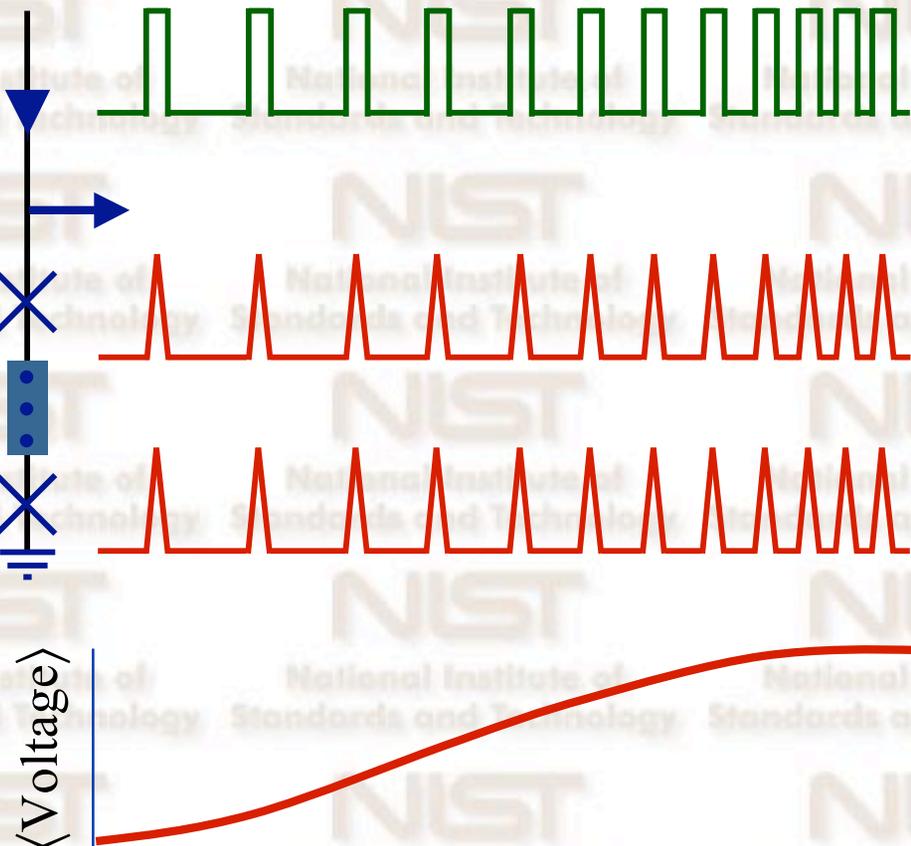
# JAWS - Digital to Analog Conversion

Digital Code Bit Pattern 00100010001000100100100101010101

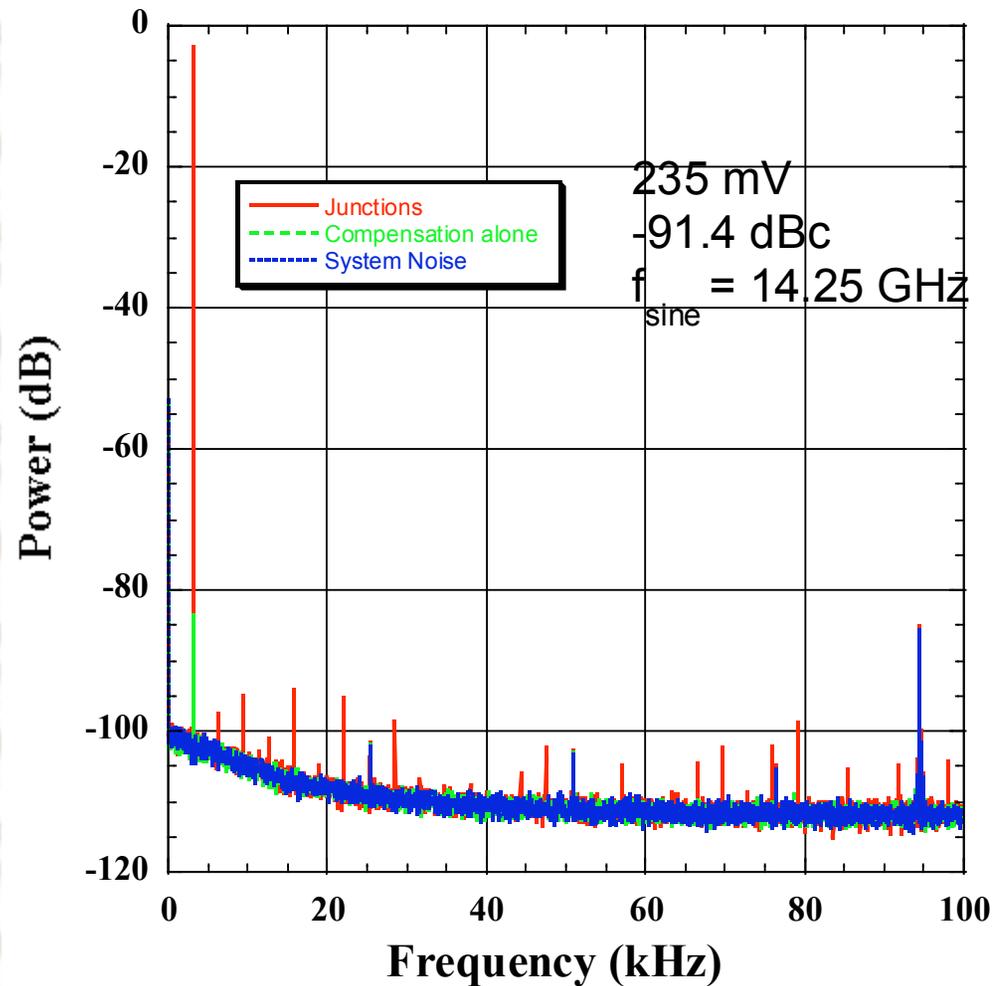
Commercial  
Semiconductor Pulse  
Pattern Generator

Array Output Voltage

Time-integrated  
Average Voltage

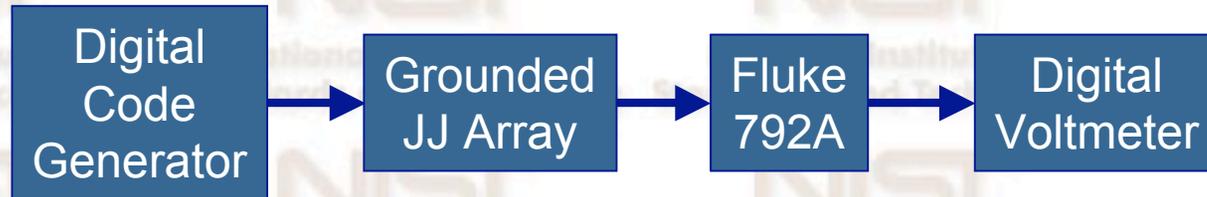


# JAWS - Performance



- 3.1 kHz sine wave
- -91 dBc distortion
- 235 mV Peak Voltage
- No margins
- Larger margins for smaller voltages

# JAWS - Ac-dc Transfer



Frequency (kHz)	Corrected Ac-dc Difference ( $\mu\text{V/V}$ )		
	Both	Left	Right
1.25	+3.0	+4.0	+4.0
2.5	-0.5	-0.5	-1.5
5	+1.3	-1.5	+1.5

Input: 100 mV

# Consistency between FEM and AEM Groups

- To establish consistency between groups for 792A calibrations:

Used CCEM-K11 792A calibrated by both groups by different methods

Used customer calibrations for 792A → 792A intercomparisons

# CCEM-K11 Measurements

- FEM Group

- Direct intercomparison to MJTC at 100 mV

- No scaling from 2 V primary standard

- Comparison to 792A calibrated by AEM Group

- AEM Group

- Comparison to 792A

- From primary standard through step down chain

# Scaling

0.85	2 V		
		1 V	0.98
1.10	500 mV		
		250 mV	1.20
1.30	100 mV		

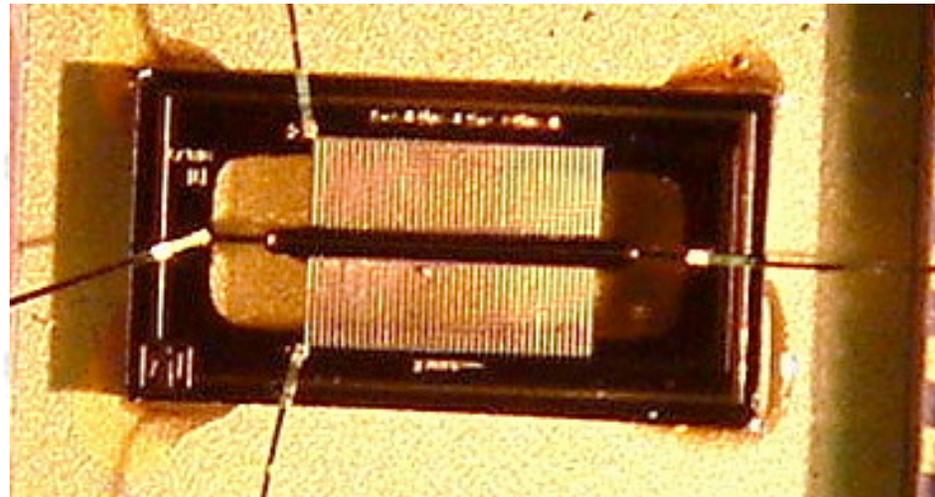
Uncertainties (in  $\mu\text{V}/\text{V}$ ) for traditional  
range-to-range scaling

# MJTCs for Low-Voltage Measurements

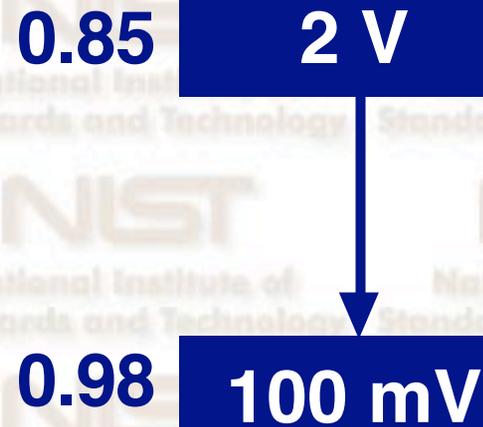
- Multijunction thermal converters used for low-voltage measurements

Ac-dc differences independent of input voltage level from 2 V  $\rightarrow$  100 mV

No additional uncertainty terms from scaling



# “Scaling” using MJTCs



Uncertainties (in  $\mu\text{V}/\text{V}$ ) for MJTCs  
With no scaling

# CCEM-K11 Results

Group/ Method	Voltage Range	Applied Voltage	Ac-dc Difference ( $\mu\text{V}/\text{V}$ )			
	mV	mV	1 kHz	20 kHz	100 kHz	1 MHz
FEM MJTCs	220	100	$+1 \pm 12$	$-1 \pm 12$	$+45 \pm 22$	$+170 \pm 68$
AEM Scaling	220	100	$+4 \pm 12$	$+4 \pm 12$	$+45 \pm 22$	$+194 \pm 68$
FEM 792A	220	100	$+6 \pm 46$	$0 \pm 46$	$+32 \pm 59$	$+181 \pm 157$
<b><math>D_i</math></b>	<b>220</b>	<b>100</b>	<b><math>-1 \pm 12</math></b>	<b><math>-3 \pm 13</math></b>	<b><math>+3 \pm 23</math></b>	<b><math>+1 \pm 78</math></b>

# CCEM-K11 Triangles

6765002

1 kHz:	+2.9
20 kHz:	+1.4
100 kHz:	+2.8
1 MHz:	-1.0

8495001

5405003

100 mV

# CCEM-K11 Results

Group/ Method	Voltage Range	Applied Voltage	Ac-dc Difference ( $\mu\text{V}/\text{V}$ )			
	mV	mV	1 kHz	20 kHz	100 kHz	1 MHz
AEM Scaling	22	10	$+24 \pm 46$	$+16 \pm 48$	$-2 \pm 59$	$-125 \pm 157$
FEM 792A	22	10	$+22 \pm 46$	$+12 \pm 48$	$+2 \pm 59$	$-98 \pm 157$
$D_i$	22	10	$+6 \pm 38$	$+25 \pm 41$	$-2 \pm 53$	$+19 \pm 152$

## Low Voltage Summary

- At 100 mV, FEM Group and AEM Group agree very well

Using three very different techniques on CCEM-K11

On several customer's 792As

- At 10 mV, FEM Group agrees well with AEM Group using a 792A calibrated by AEM Group to measure CCEM-K11
- We are confident that we can assume the full calibration of a Fluke 792A

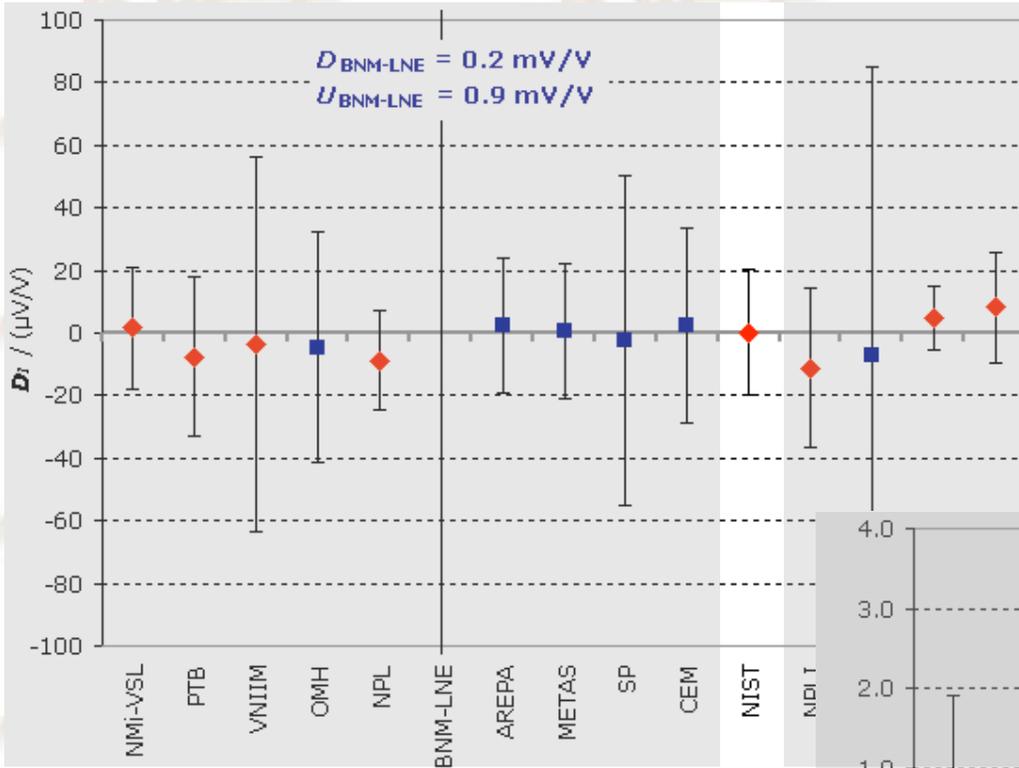
## Next Problem: RF-dc

- Quantum Electrical Metrology Division measures ac-dc difference up to 1 MHz
- Electromagnetics Division measures ac-dc difference from 1 MHz to 1 GHz

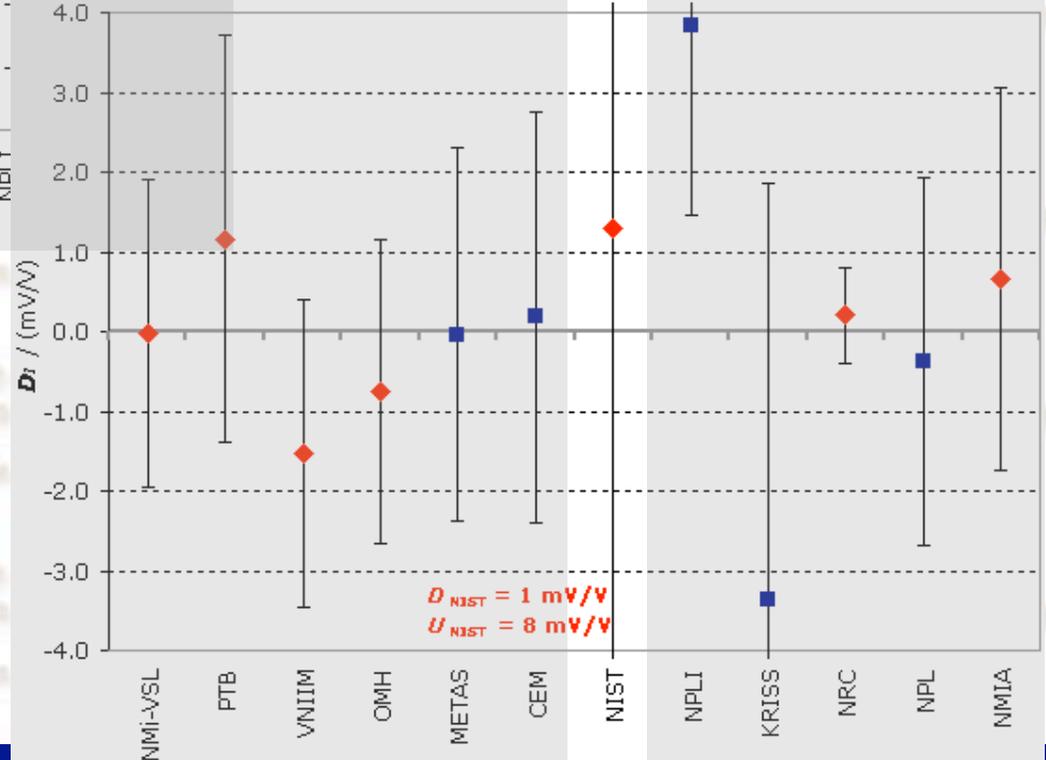
To get true broadband calibrations, a customer must ship a thermal converter to both Gaithersburg, MD and Boulder, CO

# It's not efficient for our customers!!





1 MHz



100 MHz

And embarrassing  
in international  
Intercomparisons!

# Solution

- Move the RF-dc calibration service from Boulder, CO to Gaithersburg, MD
  - Then **ALL** thermal converter calibrations will be in the same project
  - Timetable:
    - Move equipment: August 15-19, 2005
    - Test in new space: September 2005
    - Renew RF-dc calibration service to 100 MHz: January, 2006

# Problem: Ac Current Measurements

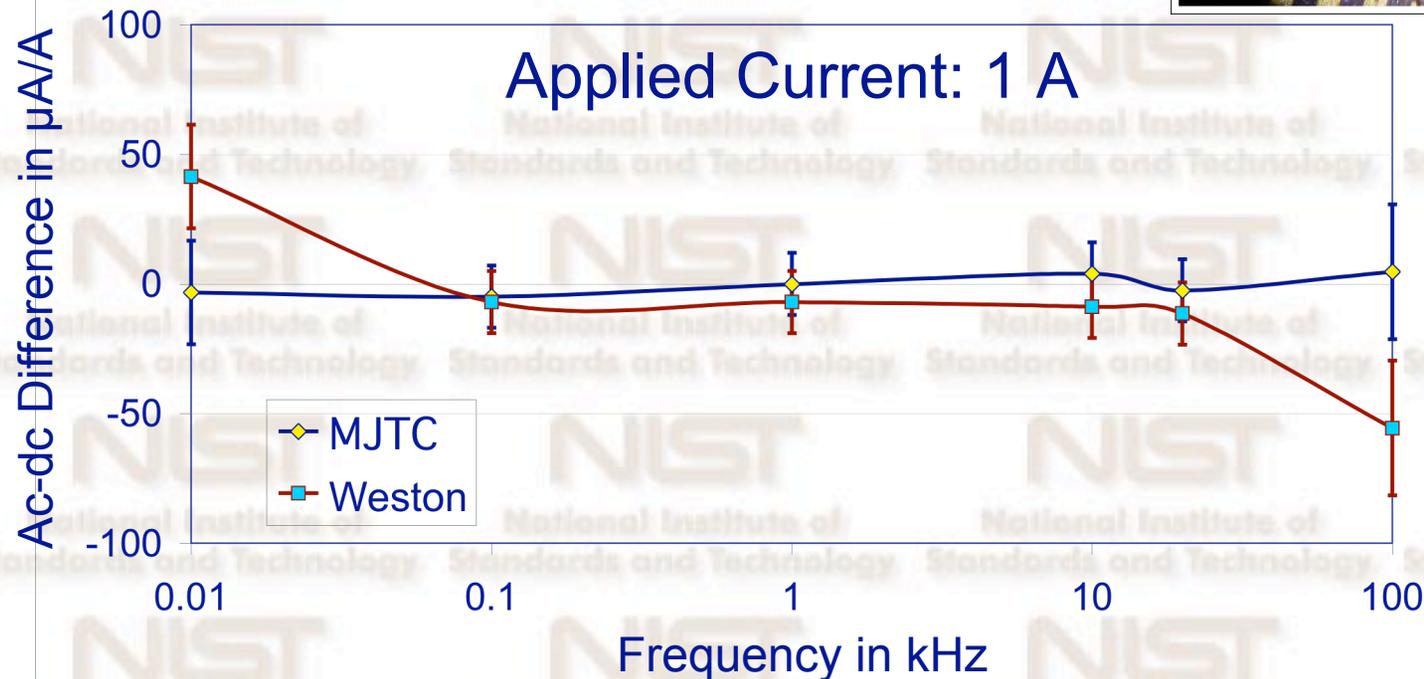
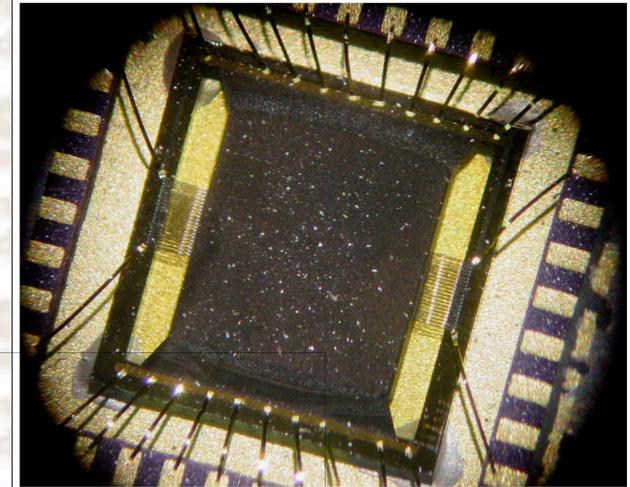
- NIST requires new standards for ac current metrology
  - Present high current thermoelements failing
  - Independent of shunts
  - Present research focused on MJTCs
    - Reported at NCSLI 2004
    - Fabrication now at NIST

# Solution

- Fabricate thin-film MJTCs

Reported at NCSLI 2004

Fabrication now at NIST



Collaborator:  
J. Beall,  
NIST  
Boulder, CO

## Plans for Next Year

- Continue development of ac JVS at higher voltages
- Continue fabrication of high-current MJTCs
- Begin development of high-frequency MJTCs
- Fully absorb RF-dc calibration service
- Assume all Fluke 792A calibrations

# Acknowledgements

- CCG 441 (development of MJTCs)
- NIST Division 817/Calibration Surcharge (low voltage, RF-dc difference)

## Our PR Firm

- Johnson, Young, Young, Williams, Rudd

